Asymmetric Circular Array Antenna Synthesis Based on Angular Positions

Mangolika Bhattacharya, Sudipta Das, Durbadal Mandal, and Anup Kumar Bhattacharjee

Abstract—**In this paper, a broadside circular array antenna resting on *x-y* plane is assumed. Design aim here is to obtain the optimal combination of non-uniform angular positions of the elements and uniform radius for the array, so as to acquire the radiation with the lowest possible sidelobe peak (SLL) with least possible first null beamwidth (BWFN) increment. Optimum angular locations of elements are found using Real coded Genetic Algorithm (RGA).**

Index Terms—**Circular array, asymmetric circular array, sidelobe reduction, optimal angluar location, real coded genetic algorithm.**

I. Introduction

A mass of research operations have been conducted in the previous few decades on various antenna array structures in order to acquire shrunken relative peak sidelobe level and the first null beamwidth [1]-[28]. Antenna Array is constituted by congregation of radiating elements in an electrical or geometrical conformation. Entire field of the Antenna Array is calculated by vector summation of the fields radiated by each single element. A circular array has all its elements placed along a perimeter of a circle. Circular array is a layout that has a contour of huge practical involvement. Its application span extends in radio detection finding, air and space navigation, underground propagation, radar sonar and many other systems. The aim of antenna array geometry synthesis is to assess the physical setup of the array that produces the radiation pattern that is nearest to the desired pattern [29]. Various kinds of works have been carried out to modify the radiation pattern of basic and concentric circular arrays by optimizing its geometry. Major aspects of optimizing circular geometry include sidelobe performance improvement [2], [17], [18], [22], [28]; adaptive-beamforming [13]; mutual coupling [21]; thinning [25] etc. In this paper the design aim is to inhibit the proportion of the maximum sidelobe level (SLL) to main beam level for a circular antenna array. Besides suppressing maximum relative sidelobe level the goal is to inflict nulls for each and every peak of sidelobe and simultaneously conserving the nulls of the initial pattern at their locations as well as to restrain the dispersion of main beam. In the present case, the angular positions of elements and the radius of the array are chosen as the parameter for qualifying the radiation pattern. A radiation pattern with lowest SLL, more and deeper nulls, and, slenderer main beam is advantageous in the present case. RGA [30] is employed in this paper to obtain the desired pattern [7], [26], [30].

Remaining of the paper is formatted as follows: in section II, the general design equations for the non-uniformly placed asymmetric circular antenna array are stated. Then, in section III, RGA is presented in brief. Numerical simulation outcomes are demonstrated in section IV. Finally the paper concludes with a summary of the work in section V.

Manuscript received February 25, 2012; revised April 26, 2012.

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II. Design Equation

Figs. 1 and 2 depict the geometry of a circular array of N isotropic sources is laid on x-y plane having a radius a and scanning at point P in the far field. Array factor ($AF(\theta,\phi)$) of such an array can be given by (1) [30].

$$AF\ (\theta,\phi) = \sum_{n=1}^{N} I_n e^{[\,jka\ \sin\theta\cos(\ \phi-\phi_n\ )+\alpha_n\,]} \tag{1}$$

where,

I_n = individual excitation amplitude,

$k = 2\pi/\lambda$, λ being the wavelength of operation,

θ is the azimuth angle,

ϕ is the elevation angle,

ϕ_n is the angular location of nth element along *x-y* plane.

$\alpha_n = -ka\sin\theta_0\cos(\phi_0-\phi_n)$

(θ_0,ϕ_0) is the desired direction of scanning. Therefore there should be maxima of $AF(\theta,\phi)$ at that point. In the present case, the maximum scanning is required along the *z*-axis. Therefore, $\theta_0 = 0$ for this case. Moreover, in the paper, the pattern in the *x-z* plane is taken for experiment. So, $\phi = 0$ in the present case. Thus, (1) changes to,

$$AF(\theta,\phi_n) = \sum_{n=1}^{N} I_n e^{jka\sin\theta\cos\phi_n} \tag{2}$$

For initial case, ϕ_n was equal to $2\pi n/N$ i.e. all the elements were uniformly spaced. Initial radius for each structure is taken as $3\lambda/\{8\sin(\pi/N)\}$.

The design goal in the present case is to find the optimum set of values of ϕ_n in order to get the minimum SLL for least BWFN increment. Element positions along the perimeter are varied asymmetrically and simultaneously a probable optimal radius is found in order to get the desired pattern in the present case. A radiation pattern that gives lowest possible SLL and thin BWFN is preferred for this case.

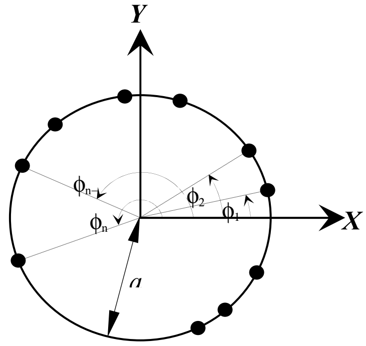

Fig. 1. Geometry of *N* element Asymmetric circular array of isotropic radiators (Top View)

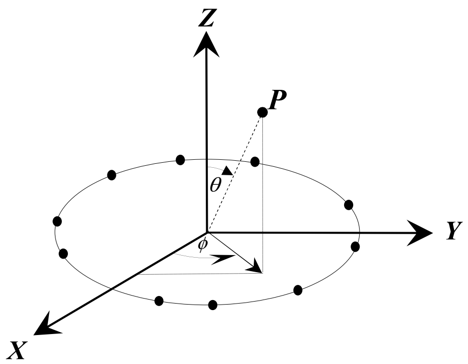

Fig. 2. An Asymmetric circular array laid in the *x-y* plane with *N* isotropic elements scanning at a point *P* in the far field

The Cost Function is designed to make the problem a minimization problem. It is designed in such a way that, reduction of SLL in both the upper and the lower bands without significant increment in the BWFN causes lowering of cost function. In the present case the fitness function or the cost function "CF" is taken as below,

$$CF = \frac{SLL_{initial}}{SLL_{current}} + \left|AF(\theta_i,\phi_n)\right|^2 + \left|BWFN_{initial} - BWFN_{current}\right| \tag{3}$$

where,

$$SLL_{initial} = 20\log_{10}\left(\frac{0.5\times\left|\begin{array}{l}AF\left(\theta_{msl1_{initial}}, I_{initial}\right)\\ +AF\left(\theta_{msl2_{initial}}, I_{initial}\right)\end{array}\right|}{\left|AF\left(\theta_0, I_{initial}\right)\right|}\right)$$

$$SLL_{current} = 20\log_{10}\left(\frac{0.5\times\left|\begin{array}{l}AF\left(\theta_{msl1_{current}}, I_{m_{current}}\right)\\ +AF\left(\theta_{msl2_{current}}, I_{m_{current}}\right)\end{array}\right|}{\left|AF\left(\theta_0, I_{m_{current}}\right)\right|}\right)$$

In the present case, θ_0 is the angle where peak of the main lobe is attained in $\theta \in (-\frac{\pi}{2},\frac{\pi}{2})$. $\theta_{msl1_{currrent}}$ is the angle where the maximum sidelobe $\left(AF\left(\theta_{msl1_{currrent}}, I_{m_{current}}\right)\right)$ is attained in the lower band and $\theta_{msl2_{currrent}}$ is the angle where the maximum sidelobe $\left(AF\left(\theta_{msl1_{currrent}}, I_{m_{current}}\right)\right)$ is attained in the upper band for the current iteration. Similarly, $\theta_{msl1_{initial}}$ is the angle where the maximum sidelobe $\left(AF\left(\theta_{msl1_{initial}}, I_{initial}\right)\right)$ is attained in the lower band and $\theta_{msl2_{initial}}$ is the angle where the maximum sidelobe $\left(AF\left(\theta_{msl1_{initial}}, I_{initial}\right)\right)$ is attained in the upper band for the initial case. If the currecnt iteration has the lower SLL, the 1st term will get reduced and hence cost function will be reduced. So, the first term in (3) is used for minimizing the SLL.

The second term in (3) is used [16] to introduce nulls in each and every direction outside the main beam. Thus this term, in the present case is used to reduce sidelobe level in each iteration.

In (3) the two beamwidths, $BWFN_{current}$ and $BWFN_{initial}$ basically refer to the computed first null beamwidths in radian for the non-uniform angular positions case and for uniform angular positions (initial case) respectively. So, the third term of (3) [25], [26] restricts the spreading of the main beam as far as possible. The Real coded Genetic Algorithm (RGA) employed for optimizing the angular locations of the elements, resulting in the minimization of CF .

III. Real Coded Genetic Algorithm (RGA)

GA is mainly a probabilistic seeking technique, establised on the rules of natural selection and evolution [27]. At each generation it conserves a collection of adoptees where each adoptee is a encrypted kind of a possible result of the problem at hand and called chromosome. Chromosomes are created with genes of arbitrary values between (0, 1). Each chromosome is valuated by a function known as fitness function, which is generally the cost function or the objective function of the matching optimization problem. In our case the cost function "CF" is given by (3).

Steps of RGA as applied for optimization of Angular Locations of Elements for Asymmetric Circular Array Antennas are [7]:

- Initialization of real chromosome strings of n_p population, each constituting of a set of Angular Locations of Elements. Size of the set counts on the number of antenna elements in a specific array design.
- Decipherment of strings and evaluation of CF of each string.
- Extraction of elite strings in order of increasing CF values from the minimum value.
- Copying of the elite strings over the non-selected strings.
- Crossover and mutation to generate off-springs.
- Genetic cycle updating.

The iteration stops when the maximum number of cycles is reached. The grand minimum and its matching chromosome string or the desired solution are finally obtained.

IV. Results of Simulation

This section gives the simulated results for various linear antenna array designs optimized by RGA technique. Three sets of Circular array structures having 16, 18, and 20 elements are considered, each having uniform excitation coefficients of the elements.

The parameters for the RGA are set after many trial runs. It is found that the best results are obtained for an initial population of 120 chromosomes. Maximum number of Generations N_m is limited to 250. For selection operation, the method of natural selection is chosen with a selection probability of 0.3. Crossover is randomly selected dual points. Crossover ratio is 0.8. Mutation probability is 0.04.

Table I shows the maximum sidelobe level and the BWFN for all the sets of asymmetric uniform circular array antenna designs having the initial uniform angular spacing variable as $\phi_n = 2n\pi / N$.

Table II gives the optimal individual non-uniform angular spacing varied asymmetrically in the range (0°, 360°) with optimal radius. Optimal non-uniform angular locations along with optimal radius for 16, 18 and 20 element asymmetric circular array are tabulated here. These values corresponding to each set are calculated using (2) and the fitness function as described in (3). In this table results are found for $\phi_n \in (0,2\pi)$. In both the tables SLL and BWFN are expressed in dB and degree respectively. In Table II optimal angular locations are also expressed in degree.

A. Analysis of Radiatin Pattern of Asymmetric Non-Uniform Circular Array Sets

Figs. 3-4 examine and compare the initial radiation pattern of the 18 and 20 elements asymmetric uniform circular antenna array with corresponding asymmetric circular antenna array with optimum non-uniform angular locations of elements respectively.

TABLE I: MAXIMUM SIDELOBE LEVEL (SLL) AND FIRST NULL BEAMWIDTH (BWFN) FOR DIFFERENT SETS OF ASYMMETRIC CIRCULAR ARRAY ANTENNA WITH UNIFORM EXCITATNON AND UNIFORM ANGULAR SPACING

No. of Elements (El.)	Initial max SLL (dB)	Initial BWFN (°)
16	-7.90	23.00
18	-7.90	20.50
20	-7.90	18.30

TABLE II: MAXIMUM SIDELOBE LEVEL (SLL) AND FIRST NULL BEAMWIDTH (BWFN) FOR DIFFERENT SETS OF ASYMMETRIC CIRCULAR ARRAY ANTENNA WITH UNIFORM EXCITATNON AND UNIFORM ANGULAR SPACING

El	Optimal Angular Locations of elements froom positive *x*-axis(°)	Optimal Radius (λ)	Final SLL (dB)	Final BWFN (°)
16	5.07 53.39 56.78 85.02 97.57 102.76 227.34 239.37 251.29 256.00 274.87 277.05 282.50 288.26 299.08 326.14	2.46	-18.43	33.60
18	0.67 45.04 62.42 75.64 87.19 94.91 96.37 105.57 129.59 164.28 230.46 245.62 252.48 277.98 283.69 298.46 309.33 331.77	2.16	-21.38	31.80
20	0.42 43.20 54.52 66.75 3.49 87.63 99.66 108.0423 111.68 121.31 135.06 145.06 184.53 235.03 258.02 268.87 274.77 281.76 297.31 322.33	2.40	-19.64	27.20

These figures are framed straightaway from the values of corresponding sets of Tables I and II respectively. From the figures it is illustrated that optimizing with (3) enriches the radiation pattern by decreasing the SLL.

It can be viewed from the figures and tables that SLL reduction has been attained at the cost of BWFN. As seen from the Table II, an asymmetric circular array antenna with optimal non-uniform angular locations of elements has SLL reduced to -21.317 dB and -19.643 dB against -7.90 dB and -7.90 dB for the set having 18 and 20 elements respectively.

B. Convergence Profile of RGA

The minimum *CF* values against number of iteration cycles are registered to obtain the convergence profile of each set. Figs. 5 and 6 displays the convergence profiles of minimum *CF* of non-uniform asymmetric circular antenna array set having 18 and 20 elements respectively. It can be viewed that the convergence curve of an 18 element circular antenna array converges after 150 iterations, and, the convergence curve for 20 element array converges after 180 iterations. The programming has been written in MATLAB language using MATLAB 7.5 on core (TM) 2 duo processor, 1.83 GHz with 2 GB RAM.

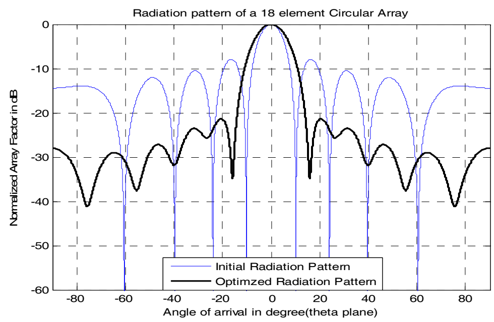

Fig. 3. x-z plane Radiation pattern of a 18 element asymmetric circular array on the x-y plane

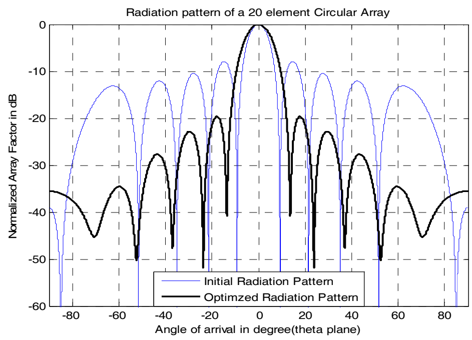

Fig. 4. *x-z* plane Radiation pattern of a 20 element asymmetric circular array on the *x-y* plane

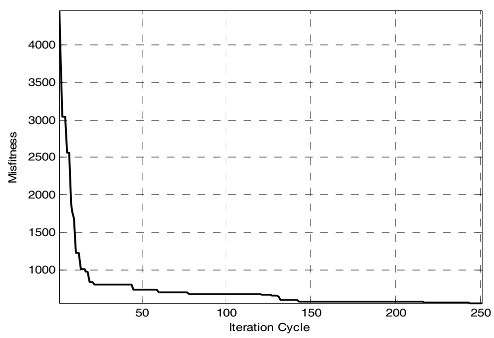

Fig. 5. Convergence profile for a 18 element non-uniform asymmetric circular array antenna using RGA.

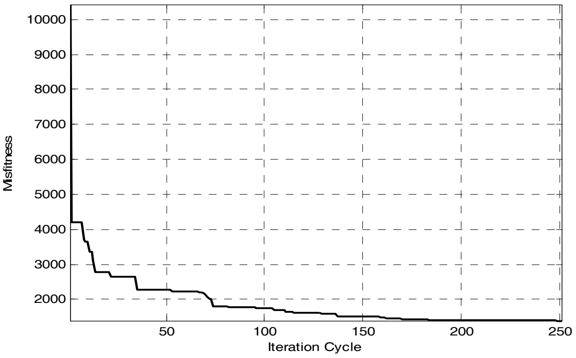

Fig. 6. Convergence profile for a 20 element non-uniform asymmetric circular array antenna using RGA.

V. Conclusion

In this paper, the design of an asymmetric circular array antenna with non-uniform angular spacing between the elements has been depicted applying the proficiency of RGA. Simulated results reveal that optimizing the radiation pattern by changing the references asymmetrically causes vanishing of deep Nulls. Again, varying the same non-uniformly provides an appreciable SLL reduction and more Nulls with respect to corresponding circular array with consistent angular spacing amongst elements.

The asymmetric linear antenna array sets having 18 and 20 elements optimized using cost function as in (3) have the final SLL reduced to -21.38 dB and -19.64 dB against -7.90 dB of initial value respectively. The results for these sets show that the radius tends to take its initial value. Again, the corresponding optimized radiation pattern has some extra nulls.

Hence, with the help of RGA a circular array antenna with lower interference from the unwanted directions is reconstructed with slight sacrifice in directivity. Thus, the RGA technique is anticipated to be a very bright evolutionary optimization technique for the global optimization of any antenna array design problem.

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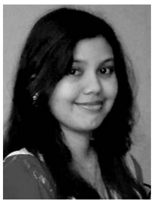

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